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III.

Researches upon the Origin, Mode of Development, and Nature of the SPERMATIC PARTICLES *among the Four Classes of Vertebrated Animals.*

BY WALDO J. BURNETT, M. D.

(*Communicated July*, 1850.)

IN the minds of those who are interested in, or have pursued, physiological studies, there appears to be a kind of predilection for that branch relating to the primitive conditions of being. The existence of an animated being, and the modes of its continuation, considered as physiological facts, are such mysteries, that the mind naturally turns, for the removal of these obscurities, to the very conditions attending its primitive elimination.

To watch the new being, as it arises from an amorphous mass, starting into life, gathering constantly the material forms for the expression of its type, — to watch its gradual growth until it shall burst forth a living, thinking being, — to do all this has, without doubt, been the source of higher delight, and of a happiness more transcendently pure, than that afforded by any other study in which the scientific mind has ever been engaged. It has been, perhaps, for this reason, that, from the earliest days, and more particularly since those of available artificial optics, men of nearly every civilized part of the world have been devoted with an untiring patience to the most thorough and correct study of embryology; a branch of knowledge which can boast of more details, and yet which is more unfinished, than any other in physiology.

All studies of this kind are attended with difficulties of no usual character. Nature, if I may so say, appears to have taken care that the finest expressions of her wisdom and skill should be located in the most recluse situations. The paraphernalia surrounding the production of a new being are in exact accordance with the importance of that process. To these difficulties may be added those of the minuteness and delicacy of the objects. One would suppose that these latter difficulties might have been done away in the present condition of optical science. In some respects they have been, but in others they never have been, and never can be. It is rather a remarkable fact, that most of the material objects actively concerned in the processes of reproduction have a delicacy such as is nowhere else found, and such as evades our correct appreciation of their character by any mode of illumination. So that, while the grosser parts (if I may so call them) in this department are well understood, it has been within the few past years only that those of a more minute, and perhaps, on that very account, of a more important character, have been pursued.

The study of the growth of the impregnated germ has a counterpart at least as important in the study of the means of that impregnation.

Every thing connected with our existence is enveloped in wonder, and the man of science, standing on material facts, is continually brought to the knowledge of the truth, that he can go no farther. However this may be, and however wonderful all around us may seem, yet the mind recognizes degrees of these wonders and of our ignorance, and this according as they are with or without analogy, or have or have not preliminary facts with which we may start. And I do not hesitate to affirm, that the fact that the simple, minute particles of one being should, by the mere agency of contact, not only give rise to a living whole, but in this way convey to it many of the moral and physical properties of the being of which it comes, — all this has a wonder about it more mysterious than any other phenomenon with which the man of science has to do.

It is for this reason that I have for a long time thought, that a course of study to ascertain the real nature of these fecundating particles of the male, the Spermatozoa, has an importance paramount to that of what may be called the secondary processes, included under the name Embryology.

Although attention to the study of the Spermatozoa dates back a long time, yet it is within a few years only that researches of value have been made. I know of no better example in science how a single false conception of an object is a source of constant retardation of its progress, than that furnished by the Spermatozoa. The notion that they are animals, adopted when they were first known, and continued until within a few years, was of itself a sufficient bias against any knowledge of their true character. Such has been the opinion of Czermak,* who regarded them as *Vibrios* ; of

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* *Beiträge zu Lehre von den Spermatozoiden.* Vienna, 1833.

Valentin,* who thought he had seen traces of a high organization in those of a bear, which has since been shown to be a delusion; of Gerber,† who was certain he perceived organs of generation in those of the *Cabiai;* of Schwann,‡ who thought he perceived in those of man a sucking lip; of Pouchet,§ who fancied he saw a digestive system, and has given figures to that effect. I cannot here stop to speak of the fanciful figures found in the *Suites à Buffon*, where objects appear to have been seen rather as the observers would wish them to be seen, than as they really were.

The whole amount of these observations seems to be based on the assumption, that, as they were animals, they must at any rate have an animal structure, a view which the philosophers (perhaps not their observations) bore out. To Wagner || and to Kölliker ¶ we are indebted for researches far more trustworthy, and which have shed a great degree of light and interest upon the subject. Most of what is really known about these particles is referable to these men and their co-laborers. I shall not here refer to the grounds in support of the view that they are not animals; they will come up more fittingly another time.

I have thus, as a prologue, referred to the general condition of the subject, a digression which could hardly be excused, considering the vague manner in which it even now presents itself to the minds of many.

I should consider that I had not begun my subject at the beginning, did I not preface the more minute details of microscopic structure with some general remarks upon the secreting male or testicular organs, which alone, throughout the animal kingdom, are the tissues from which these particular bodies are eliminated.

Physiologically speaking, the testicles are, like all the other organs of the animal body, endowed with a peculiar function, — simply a basement tissue, on which the peculiar secreting tissues rest. And throughout the whole vertebrated kingdom this secreting tissue has, anatomically, common characters, the differences of these organs being traceable to the mode of the packing of the tissue, and the means for its more or less constant production. As to this latter point, there is the same grade preserved as appears in the other characters of the types.

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* *Repertorium*, 1837, p. 134.

† *Allgemeine Anatomie*, p. 210.

‡ *Mikroscopische Untersuchungen.* Berlin, 1839.

§ *Théorie positive de l'Ovulation spontanée et de la Fécondation*, p. 321. Paris, 1847.

|| *Histoire de la Génération et du Développement*, p. 26. Bruxelles, 1841.

¶ *Beiträge zur Kenntniss der Geschlechts-Verhältnisse und Samenflüssigkeit Wirbelloser Thiere.* Berlin, 1841.

In fishes, the lowest vertebrates, we find the structure of the testicle the most simple. And even here, we perceive a grade as to their two grand divisions, marking differences as wide as those of their other characters. In the Plagiostomes and Cyclostomes the structure of the organ does not appear to have risen above the primitive cellular type, that is, it is but a collection of parent cells, which have never advanced to the condition of losing their identity as such by passing into seminal tubes.

In the higher osseous fishes, a higher condition of things exists. There is an advancement beyond the cell-type, and the large cells appear to have passed either into tubes or bundles of transverse folds, on the inner surfaces of which the parent sperm-cells are produced, as before they were inside the large cells of those of a lower character.

The prolific nature of the testis, as a secreting organ, is just in proportion to these convolutions and variations. And we find this prolificness in a ratio corresponding to the liabilities of the semen reaching the ova of the females. Thus, in the lower orders, the species of which are dormant and sluggish in their character, and which are almost constantly in contact with the bottom of the water, the quantity of sperm to insure the continuation of the species is necessarily less than in those higher and more active orders, where, from their constant movement and travelling, the contact of the two may be looked upon more in the light of an accident than otherwise. If, then, we are allowed to reason on the relation of things, I think that in this fact may be found the reason of the larger and more fertile character of the testes of the higher fishes.

Among the *Reptilia*, *Aves*, and *Mammalia*, with which the process of fecundation takes place only by the conjunction of the sexes, a different and stricter economy is manifested. The testes are more compact, their product less in quantity, and the value of this quantity is shown by the means adopted for its contact with the ova by efferent ducts, receptacles, and an intromittent organ.

With these three grand classes, I need not refer to the differences of size and external character everywhere met with; they bear not at all upon the grand type of testicular structure, but are referable to the economy of the species to which they belong. And only this much may be mentioned, that, generally speaking, as we approach nearer and nearer the higher forms, the size of the testis compared with the whole body is less and less, and the prolificness of the animal is less and less, because, perhaps, the liabilities for the destruction of the species are in the minimum.

We have now the organs for the elimination of the sperm. Our next inquiry is, What are the preliminary steps of that process?

There is, in all the real glandular organs of the animal body, a common structure. This is a layer or layers of epithelial cells, situated on a basement membrane, which last is conformable to the structure of the organ generally. And I think it pretty clearly settled now, that all the products of secretion are the results of the functions of these cells ; that is, the elaboration of bile or milk, for instance, is accomplished by the material transuding the walls of these cells.*

Considering the testicle as a glandular organ, it is a matter of considerable physiological importance, to ascertain if its epithelial lining serves as the real secreting tissue of the sperm. In other words, if parent sperm-cells are not epithelial cells. In the very able and complete article entitled "Semen," by Drs. Wagner and Leuckardt, in *The Cyclopædia of Anatomy and Physiology*, this question is raised and discussed, but no positive opinion given, as they think it not yet mature.

I have had the good fortune to conduct some observations bearing upon this point with success. The result of these may be briefly stated as follows. The tubes of the testes of animals which have not arrived at the age of puberty have a simple epithelial lining, the cells of which do not differ at all from those of a *pavement form* covering mucous membranes. When, however, the animal begins to have the generative impulses, the character of the cells seems in a manner modified ; they appear to pass to a higher grade of function, exactly as do those of the mammary gland at the time of lactation, and this without losing their primitive type as epithelial cells. It may be thought that the thin vesicular character of the parent sperm-cells would separate them distinctly from the category of epithelium ; but this difference can, I think, be considered only as an expression of their higher relation and function.

Of this much I feel pretty certain, and, aside from the facts just mentioned, it may be considered as deciding the matter, at least as far as can be in questions of this kind :

We see in the field simple nucleated cells, differing from the common epithelial cells in no respect, except their slightly increased size. By the side of these, perhaps, we see a similar cell with the nucleus divided, and then, again, these divided nuclei subdivided, and so on, the original cell simply dilating, being thinned and rendered quite transparent ; and this process goes on until the embryology of the Spermatozoa is completed, the whole being referable to an epithelial cell, undergoing the highest metamorphoses attainable by cell-structure.

Our next inquiry is, What is the histology of *these* epithelial cells ? For an *exposé* of this part of our subject, I must refer to my former investigations on these matters.

This is, in brief, that the cells arise from minute hollow nuclei, — consisting most probably of a particle of oil, having an albuminous envelop (the *haptogen membrane* of

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* See an article in the July number of the *American Journal of Medical Science*, upon Epithelial Structures.

Acherson), — which, by expansion from endosmosis, become hollow vesicles, inside of which are formed nuclei, by a kind of condensation of their granular contents, they then being nucleated cells. This mode of cell-formation, and which, as far as my observation goes, is *the* mode of cell-genesis in the animal economy, differs, it will be seen, essentially from that set forth by Schwann and Schleiden, as to these two points, viz. : — 1st. That the nucleus and cell are one and the same as to their histological character; and 2d. That the cell precedes, as to its formation, its nucleus, instead of the reverse.

These histological facts are more than interesting, because, as I have stated in another place, Professor Agassiz, in his studies of the formation of the ovum, has arrived at the conclusion that the primitive cell, on which the ovum starts, (and this, I have no doubt, is an epithelial cell from the lining membrane of the ovary,) arises in the same manner. And the bearing of this will be the more forcibly seen, as we pass on to show that the formation of Spermatozoa is strictly but a miniature embryology.

Having thus passed the preliminaries of our subject, concerning which little has hitherto been done, and about which, therefore, little has until now been known, we next come to a section to which the direct processes of the formation of the Spermatozoa belong, and upon which most of the labors in this direction have been spent. That it may appear that I do not ignore what has been done in former times, it will be proper for me to allude briefly to the history of this subject.

Although this subject has been one in that category which has been pursued since the days of *assisted* optics, yet most of what is valuable may be dated only as far back as the early labors of Siebold.* These were soon followed by those, well marked for their elaborate character, of R. Wagner.†

The researches of Kölliker,‡ however, since 1840, claim the highest credit, and it is to these that some of our clearest ideas of the "Spermatic Particles" can be traced. Kölliker was the first to break up those rude notions of the animality of these bodies, and, considering them no longer meriting the name of *Spermatozoa*, he termed them *Spermatic Particles*. I need not review the wide field over which these men have passed.

Both Wagner and Kölliker have described and figured the size and form of these bodies in very many of the genera of the animal kingdom. They have shown that they are formed inside parent-vesicles, and, according to Kölliker, developed under *five* different types; and, notwithstanding these changes have been described with a detail indicative of indefatigable labor, yet those preliminary changes which seem, as it were, to mark the philosophy of the whole process, and which make the whole analogous to the corresponding function of the other sex, — all this seems to have been overlooked, or, if perceived, to have been passed over without recognizing their significant value.

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* In Müller's *Archiv*, 1836, p. 232.

† *Fragmente zur Physiologie der Zeugung; Beiträge zur Geschichte der Zeugung und Entwickelung.* Munich, 1837.

‡ *Beiträge zur Kenntniss der Geschlecht-Verhältnisse und Samenflüssigkeit Wirbelloser Thiere.* Berlin, 1841. Also, *Die Bildung der Samenfälen in Bläschen.* Nuremberg, 1846.

Early in 1849, Dr. Charles Robin of Paris presented to the *Académie des Sciences* a memoir entitled (as translated), "The Existence of an Ovum as well in the Male as in the Female of Plants and Animals; producing, in the one case Spermatozoa, in the other the Primitive Cells of the Embryo." This memoir was submitted to a *commission*, consisting of MM. Serres, Dumas, and Milne-Edwards, and their report may be found in the *Comptes Rendus*, 1849. The grand fact of the memoir is the announcement of the fact of the segmentation of the nucleus of the male sperm-cell, as well as of the female ovarian cell of plants and animals, preceding the elimination of their special products. The memoir had more a botanical than a zoölogical import, because the data on which it rested appeared to be furnished almost entirely from vegetable, instead of animal morphology. In fact, his support of these views with reference to the sperm-cells of animals appears referrible to the observations of M. Reichert * upon the Spermatozoa of *Strongylus auricularis* and *Ascaris acuminata*. Also upon observations of his own upon one of the Acalephæ, *Rhizostoma Cuvieri*.

If M. Robin's inferences were based upon his paucity of observation alone, they certainly were not scientifically warranted, considering that M. Kölliker had then just published his memoir, in which there appeared no less than five dissimilar methods by which the spermatic particles were formed in the parent vesicles. The merit of a broad suggestion, however, certainly belongs to Robin, and I am free to admit that I have borrowed it from him; but its application, and the testing of its correctness, traced by innumerable details throughout the four classes of the vertebrated animals, I must humbly claim for myself. And, in so doing, I have not relied upon the observations of Wagner or Kölliker, but have traversed the whole field myself. In this way, I have been able to perceive what I think to be important errors made by others, as well as to travel new and unexplored grounds. I say this with that humility which belongs to all scientific investigation, and especially in the department of minute and vital morphology, where the contingencies to error and illusion are more prominent than in grosser studies.

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* It is quite remarkable that Reichert, whose observations Robin quotes in support of his theory, declares that this *segmentation* of the vitellus (the very virtue of the whole) is "une sorte d'illusion produite par la mise en liberté de vésicles préexistantes, emboîtées les unes dans les autres." Quoted from Longet's *Traité de Physiologie*, in *De la Génération*, p. 144, where reference is made to Reichert, Müller's *Archiv*, 1841, p. 523.

The grand result at which I have arrived in these investigations, and which has an importance sufficient to justify me in the details already given, and those which shall be presented hereafter, may be stated as follows: —

That, throughout the range of vertebrated animals, the morphological changes in the sperm-cell preceding the formation of the spermatic particles are identical in their character with the morphological changes in the ovum preceding the formation of the new being.

The processes are the vitalization of the sperm-cell in the male, and of the ovum in the female, by the continued segmentation of the nucleus or vitellus, until each is a mulberry mass. The changes sequent upon this are of several kinds. Two of them, however, may be mentioned as apparently the most important and best known, viz.: — 1st. The liquefaction of the segmented contents into a minute granular blastema, out of which are formed, in the one case, spermatic particles, in the other, a new being; and 2d. The immediate passage of the segmented contents; in the one case, each cell becoming a spermatic particle, in the other, masses of cells forming the organs of the embryo.

There appear to be other modes than these, both with the sperm-cell and the ovum; but they are very imperfectly understood, and may here be omitted.

I shall now take up the description of my observations in the four grand classes, commencing with the lowest: —

1st. *Fishes.* — The spermatic particles of fishes exist under two forms, and these corresponding to the two forms of their testes of which we have already spoken.

In the higher *osseous fishes*, where the structure of the testes is tubular, these bodies consist of a very minute globular or cordate cephalic portion, to which is appended a still more minute tail, the presence of the latter, however, being far from constant in all specimens.

In the *Plagiostomes*, where, as we have seen, the structure of the testicle is cellular, and not tubular, the form of these bodies is quite different; they are of a much larger size, and are long and filiform, their cephalic portion being only thickened, and gradually tapering off into a tail, which, compared with the body, is not very long. The existence of these two forms is important, as we shall soon perceive.

The formation of the spermatic particles among fishes has, as far as I am aware, been observed only in the *Plagiostomes.* And with the observations of Hallman* and Kölliker* may be found nearly all that relates to the subject. My own observations have shown this much:

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* Müller's *Archiv*, 1840, p. 467.

Each of the large testicular cells arises from small nucleated cells, situated in the stroma of the organ. I have seen them nucleated, and as small as one two-thousandth of an inch in diameter. Soon after this, each has a nucleolus, and the whole increasing, we have regular nucleated cells inside of vesicles. Soon after this, the nucleus of the cell (not the vesicle) begins to segment, until the cell is full of minute cells. The next stage at which I perceived the progress was this mulberry mass composing the nucleus or vitellus, disappearing and apparently replaced by a fasciculus of spermatozoa. (Vid. Fig. 1 - 5.) The stage of their real formation, or the metamorphosis of this granular cellular mass into the bodies, I have always failed to observe. It has, notwithstanding, appeared to me quite probable, that the filamentous bodies are formed by the gradual elongation of the subdivided cells, and this because I have seen cell-like bodies of a more or less pyriform shape, as though in a state of transition, and also because the subdivided cells appear of too small a size to admit of a spermatic particle to be formed within them.

However, according to both Hallman and Kölliker, they are formed within "vesicles of formation." Although this may be the case in many instances, yet their production *in the other way does occur in other cases.* At any rate, the discussion of these questions does not appear to bear upon the grand formula of vitalization by segmentation.

In the higher osseous fishes, where the testes are either tubular or ampullar, the formation appears somewhat dissimilar. Upon the inner surface of the tubes or ampullæ there are developed vesicles, simple at first, but which soon become nucleated. This nucleus or vitellus soon divides, and this segmentation goes on until the parent vesicle is filled with minute cells. Next, the vesicle has its cellular contents replaced by Spermatozoa, the cephalic portion of which is about the size of one of the subdivided cells, a fact which would lead me to infer that they are these last, slightly metamorphosed. I am, however, quite unwilling to entertain any opinion on this point, as my observations have not been sufficient, and as it is, of all microscopy I ever handled, the most difficult clearly and definitely to make out. (Vid. Fig. 6 - 11.)

Spermatic particles of this form do not appear to be very dissimilar wherever they occur; and of many species of several families which I have examined, the differences were far from being well marked. They consist generally of a pyriform body (the small portion in front), to which is attached, when they are fresh, a remarkably thin tail.

In my earlier observations, I denied the statement that they had a caudate portion, which was certainly true of the specimens I examined, — as they were subjected to the highest and best optical power known. Investigations of a later date, and upon specimens taken fresh from the animal, have shown that the normal spermatic particles have tails, but perhaps of the most transient nature.*

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* *Op. citat.*

Unless one has the best of eyes, and a still better instrument, I should think that they would be unwise to attempt the study of those bodies with fishes; their bodies, or rather cephalic portions, are from one eight-thousandth to one twelve-thousandth of an inch in diameter, and their tails, when present, of a diameter nine or ten times more minute, being in fact the smallest organic objects coming under the eye ot the microscopist, and the clear definition of which may be taken as a fine test for a most superior instrument.

2d. *Reptilia.* — The spermatic particles of this class have been more thoroughly and satisfactorily studied than those of any other class. This is due to their larger size and more permanent characteristics throughout their several orders. Although there are marked differences, yet they seem to have a general form, consisting of an oblong, staff-like body, to which is attached a long thin tail. Among some of the different genera of the same order, they appear so nearly alike, that, were one examining them together, care would be necessary in order to know from which genus they were taken.

My own observations have been mostly among the *Batrachia*, and the mode of development here seen may be, I am well assured, considered as expressing that of all the other orders of this class.

If, at the approach of the season of *heat*, the testicles be examined, there will be found, in the midst of the normal epithelial cells lining the tubes, others larger, and having a more opaque and prominent nucleus. These are the sperm ovules or cells. After they have increased to four or five times their original size, the granulated nucleus segments, by a slight sulcus, which gradually deepens until the whole is divided into two spheres. Each of these divides, and this subdivision goes on until the parent vesicle, which has all this time been increasing in size, is filled with small nucleated vesicles. This condition of things is replaced by the presence of the spermatic particles, sometimes scattered in a random way throughout the vesicle, but commonly in a fasciculus. (Vid. Fig. 12 - 21.)

Having thus watched the vitalizing processes immediately preceding their formation, our inquiry is here, as it has been before, — Are they formed by the elongation of the

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* Czermak (*Beiträge zu der Lehre von den Spermatozoen*, Wien, 1833) says positively that the spermatic particles of fishes have *no* tails. Dujardin, however, from his observations on the Carp, believes that they are tailed, but shows that they can only be seen *as such* when fresh. (Vid. *Annal. des Sci. Nat.*, N. S., Tom. VII. pp. 291 - 297.)

segmented cells, or are they the ultimate product of a granular mass produced by the liquefaction of these divided cells? The presence in the field of *pyriform moving* cells, of about the size of the subdivided ones, would certainly favor the former view, as these were probably cells in a state of transition. On the other hand, the presence of a fasciculus of these bodies in a parent vesicle would favor another mode of development, if the fasciculi are the result of development, and not of a *subsequent* grouping, as some have supposed.* This point I shall have occasion to refer to at another time. The grand fact of vitalization has here been seen more distinctly than in the other classes.

3d. *Aves.* — The spermatic particles of birds resemble quite closely, as to their form and other gross characteristics, those of reptiles. As they were the animals on which the first exact observations of the *genesis* of these bodies were made,† more observations have subsequently been made upon this than upon any other class, and those of a vast number of genera have been delineated.

My own observations have been made for the most part upon *Passerinæ* and *Columbidæ*, and, as there is a singular uniformity throughout the whole class as to *genesis*, those of these orders are good representatives of the whole. Exactly as in the preceding class, the sperm-cells appear on the inside of the testicular tubes among the normal epithelial cells. Segmentation here goes on as previously described, and in place of the crowded vitelline cells we have a fasciculus of spermatic particles. These, when inside the parent vesicle, are never, as far as I have seen, very numerous, but appear to bear a pretty close ratio with the number of segmented cells that the vesicle would contain. This fact will admit of two constructions; namely, either that each of these segmented cells was changed into a spermatic particle, and that, therefore, the fascicular form was from a *subsequent* arrangement; or, according to both Kölliker and Wagner, that each of these served as a "cell of development," in which a single spermatic particle was formed. The latter view is most supported by direct observation; in fact, I have never been able to see any condition looking at all like a stage of transition from a cell to a spermatic particle; but notwithstanding this, I should much hesitate offering any decided opinion. The appearance of these bodies in fasciculi, as though they might have been thus formed out of a solid mass, merits our attention here, because Kölliker has based this type of genesis on observations of this class.

According to Kölliker, there is formed inside the parent vesicle a granular mass, which splits up into the spermatic bodies. There are several facts which ought here to be considered before this view is admitted. One is, that the number of bodies composing the fasciculus appears to be in a pretty close ratio with the number of preëxisting cells the vesicle would contain; so that there appears to be a morphological connection, indicating that the structure of the cells as such does not become lost in a granular mass. This may be clearly seen in many of the Passerine birds. Again, it is difficult to conceive how a granular mass can split up into a group of bodies which have not a trace of a granular structure, at least as far as we can perceive, and especially so when many of these bodies have in their interior the remains of an old nucleus, the relics of the former cells. Lastly, it is quite common to perceive in the testicular tubes of birds fasciculi of these bodies of a size so large as shows that it could not have been attained within the parent vesicles, but is rather the result of an accidental coincidence, they having a strong tendency whenever they come together to unite in a regularly formed manner; and large groups are continually gathering as they pass along, and not broken up until forced through the vasa deferentia. This point will again come up for consideration in the general remarks upon the modes of genesis. (Vid. Fig. 22 – 28.)

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* Vid. Longet, *Traité de Physiologie*, (*De la Génération*,) p. 114.

† Wagner's *Histoire de la Génération et du Développement*, *etc.*, p. 26. Bruxelles, 1841.

4th. *Mammalia.* — The spermatic particles of this class have a uniformity as to form and shape, and a delicacy of structure, exceeding any other class. They are characterized by a broad, disk-like, neatly sculptured anterior extremity, to which is appended a tail, generally of considerable length. Among the higher orders, there is a remarkable similarity, which meets with a considerable modification in those of less rank. Both Wagner and Kölliker have illustrated these forms by many figures. My own observations have been made as to their *genesis* upon the orders *Bimana*, *Carnivora*, *Rodentia*, and *Ruminantia.* With the exception of a few important points, the same mode of procedure is observed as in the former classes. Sperm-cells appear, their nucleus is divided, and so on as in the former classes. The spermatic particles, however they may be formed, are more often found, especially in the higher Mammalia, in a free, unconnected state in the parent cell, rather than in fasciculi. In many species of the genus *Mus*, where the large size of these bodies allows them to be easily seen, I have sometimes perceived them in small fasciculi in the parent vesicle, and have often particularly noticed the fact of these fasciculi being made up of an even number of bodies, and this number corresponding to the results of segmentation, 2, 4, 8, 16, &c., thus making it exceedingly probable that these particles are not formed from a granular mass, but rather directly *from* or *in* the segmented cells. (Vid. Fig. 29 – 35.) There are some peculiarities of these bodies among some of the Mammalia, that deserve our notice.

Among the *Sciuridæ* the cephalic portion of the spermatic particle has its largest and finest development, it being a thin and quite transparent disk-like body, as though from the flattening of a cell, the two membranes coming in contact; and in it may be often seen granules of considerable size, which go to support the view of its cell-membrane origin; these disks, generally circular, have often a slightly pyriform shape, and are of a size equalling one twenty-five-hundredth or one three-thousandth of an inch in diameter. To these is appended a rather long and delicate tail. When making observations on these animals, one must be struck with the similitude of these disk-like bodies to the segmented cells floating beside them in the field.

Among the *Muridæ*, we meet with a marked peculiarity of form, such as is not met with elsewhere. It consists in a curved, sickle-shaped body, to which is appended a very long tail. This sharp, knife-like portion of the body is situated on one side, so that the spermatic particle has a rather symmetrical aspect. It is difficult to understand how they are formed in this manner, and more particularly so if we attempt to trace them to a cell-origin. The genesis of these bodies in *man* does not differ at all from that of the higher brute Mammalia. Their form and general characters are too well known to need mention, and I have seen nothing particularly distinguishing them from those of some of the *Solipedes* and *Ruminantia.*

The figures of Buffon* and Pouchet† savor so much of the fanciful, and offend so much our best notions of the most minute morphological changes, that I shall not allude to them here. And here I may as well say, that most of the spermatic particles of the Mammalia are of such character as to admit of being studied only as a whole. And even admitting the very absurd view that they are animals, I should hesitate long before I believed that any one had ever seen their *internal* structure.

I have thus rather hastily described the mode of genesis of the spermatic particles in the four grand classes of the vertebrated animals; a fuller detail would have been inappropriate, as illustrating the grand formula of their genetic morphology, which we have seen is always present.

I shall now turn to some considerations upon the alleged various modes of their production, *after* the vitalization by segmentation has taken place, especially as they bear upon the formula just stated, and the commonly received embryological changes of the ovum after segmentation.

Kölliker ‡ has spoken of five types by which they are developed, viz.: —

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* *Op. citat.*

† *Op. citat.*

‡ *Beiträge zur Kenntniss der Geschlechts-Verhältnisse, etc.* Berlin, 1841.

Type A. Each filament arises from a special cell, by the increased growth of whose walls it passes into an elongated or filamentous condition.

Type B. Out of each cell formed springs a bundle of seminal filaments.

Type C. The filaments are developed in crowds within large cells,· probably in an analogous manner to the generation of the primitive muscular fibres.

Type D. Each filament arises within a special cell.

Type E. The filaments are formed in bundles from minute granular cells, these cells becoming dissolved, as it were, into each other, and assuming a delicate filamental form.

Of these, types *A* and *D* I think I have myself observed. The other three, I think, may be included under the head of the *Fasciculus mode.* I have, on a preceding page, expressed my doubts, and the reasons for them, of the reality of this mode of genesis.

The other two forms merit our attention.

1st. Genesis *out of* nucleated cells. In the ovum fecundated and segmented we have this peculiarity; namely, that the homogeneous individual parts blend together and lose their individuality as such, for the formation of a perfect whole, the vitelline cells dissolve and mingle, and their characteristics as individuals are lost. Nevertheless, holding to the view which I have some time ago announced of cell-types as the basis of all higher types, it must be that each of these vitelline cells is a miniature and correct representation of the whole ovum; and therefore, could morphological changes sufficiently minute occur within it, it would form a new being exactly like that resulting from hundreds together.

Exactly so is it with the Spermatozoa. Each of the subdivided vitelline cells represents the whole, and instead of all dissolving together to form one large body, each forms the same body in miniature, and this is in this form accomplished by a slight modification of the cell, which forms the body or anterior extremity of the particle.

In these cases, it is very probable that the nucleus of the cell plays an important part. But whether or not it is the chief agent I am unprepared to say. This kind of elongation, this metamorphosis, has its analogue in the organizable cells of the higher tissues, and must be considered indicative of a higher vitality, seeking its expression in a metamorphosis of form above the cell grade, a view still better borne out by the fact, that, in the cephalic portions of some, the nucleus is persistent. Thus reminding one of the higher metamorphotic tissues, where the nuclei, the only indices of their former cell-days, have not passed away.

2d. Genesis *in cells.* In this case, each of the divided cells serves as a parent, in which is developed a particle. When fully developed, they rest upon the side, their cephalic portion appearing to form a portion of the parietes with the caudate portion curled around. Nevertheless, this may be considered only an accidental relation, the particle, most probably, having no relation with the parietes.

I have always noticed that in these cases the nucleus is absent, and this fact has led me to adopt the view, that it is transformed directly into the particle, the cell-membrane acting simply as a protecting shield for the process. This view would involve no new or anomalous morphological process, if we consider the real nature of the nucleus, and its relation to the parent cell; namely, that it differs not at all from the cell, except in being the active metamorphosing agent.*

Both Kölliker and Wagner have inclined to the opinion, that this form was developed on the inside of the cell by aggregated particles, exactly as *lignine* is deposited on the inner surface of vegetable cells of woody plants. This is quite plausible, but the fact, that I have seen among the higher Mammalia the *sperm-vesicles* undoubtedly filled previously with segmented cells, having, *on their inner side*, particles, and these generally four and eight in number, would seem to show that they were formed either *from* or *in* segmented cells, and became there situated afterwards.

The *tail* of the spermatic particle, from its constant presence, has most probably an inappreciable importance.

As to their genesis, I do not think it referrible to exactly the same processes as those of the body proper. It appears to be a subsequent formation, and not formed from either the cell or the nucleus, but rather from a minute granular matter.

The parietes of the parent vesicle of most of the spermatic particles of Mammalia have a delicacy amounting almost to real transparency. It is difficult to conceive of an organized structure having a fineness more delicate than this ; and yet the very spermatic particles formed within have tails far more delicate than this membrane as to thickness.

Among the osseous fishes, the tail has a still greater delicacy of structure, and it would be very absurd to suppose that these are formed from a cell-membrane, since this last is formed of *layers* of granules, each of which very granules has a diameter equal with the tail itself, and perhaps larger. Moreover, it not unfrequently occurs, that, within the field you are viewing, there are some bodies with no tails. And I have noticed, that, during the unprocreative season among the lower classes, a few spermatic particles are formed, but they are generally deficient as to tails. This may easily be seen with some of the common Batrachians.

These two facts, and another, that these bodies generally lose their tails with their vitality, have led me to adopt the opinion, that this portion is intimately connected with their vitality, and that generally of the whole process of their elimination. It would seem to be this wise: after the cephalic portion has been formed, the minute organic granules with which it is surrounded begin to take a linear arrangement at one of its extremities, and by this means, modified by the type of spermatic particle in question, the tail of variable length is formed. This will account for its excessive tenuity and the variations in its length. Of course, when the vitality of the particle has ceased, the tail would, as a granular body, be the first to lose its integrity, and therefore drop off. During the intervals of the procreative period, when the sexual impulse is passed, and the corporeal forces are abstracted from the testicular organs, the elimination of these bodies must be less perfect than at any other time. Less vitalized organizable blastema is thrown out, and of course less of the primitive granular matter formed.

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* Vid. *Transactions of the American Association for the Advancement of Science*, 1849, p. 261.

This would account for the fact above mentioned, that the spermatic particles of the Batrachians in the month of October do not generally have tails, or, if so, they are short and imperfectly formed.

In this connection I ought to mention a fact M. Lallemand * has noticed in patients broken down by seminal losses. It is, that, in these cases, the spermatic particles are imperfectly formed, their tails being rough, irregular, and indistinct.

This mode of the genesis of the filamentous portion of the spermatic particles is not without its very apt analogue in the common morphology of tissues. In the process of inflammation, this granular blastema is thrown out in abundance, and that portion which does not take the organization of pus or other cells, is very apt to form by a single aggregation in a linear way that *fibrillated* structure, extremely delicate, met with in inflammatory products.

The Motion of Spermatic Particles.

This, from several considerations, should claim our attention for a few moments. I think there can be but little doubt, that the movements are effected by means of the tail, and therefore expressive of the vitality of the body. But I should be unwilling to assert that these movements are entirely due to this organ, since among some of the *Articulata*, and especially with some of the *Arachnidæ*, no tails are found.

It is useless here to discuss a question, when we have no data to stand upon. Of the whole class of cell-motions we know nothing, excepting that they are purely molecular, and are indicative of the higher vitality of these molecules. We have yet to learn every thing about *any* animal motion, and my own impression is, that all (muscular, &c.) will be found to be essentially molecular, or belonging to molecules, which are the first expressions of vitality, and serve as the basis of all organized tissues whatsoever. During my investigations, I have tried the influence of various agents. Electricity had no well-marked effect. But all those chemical agents that infringed affinitively upon the material structure, thereby impairing their integrity and vitality, put a stop to the motion. All my own experiments went to show that all these movements were identical in character with those of the cilia of epithelial cells, a matter that I have fully discussed in another place.[*]

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* *Des Pertes Séminales involuntaires.* Montpélier, 1841. Also, *Annal. des Sci. Nat.*, Tom. XV. p. 30.

Signification of Vitelline Segmentation.

Before closing this interesting subject, I have thought it essential to a clear understanding of the whole ground of analogy existing between the sperm-cell and the true ovum, that a survey should be taken of the process of segmentation and its meaning, since it forms the basis of the analogy. We will take it up as studied with the ovum.

The earliest phases of change the observer is able to perceive with the fecundated ovum is the fissuration of the vitellus. Upon a single surface of the vitellus, a kind of retreat of substance from a given point occurs; this produces a slight sulcus, which, deepening, divides the vitellus into two spheres. Upon each of these spheres the same process is repeated, and this goes on increasing in a geometrical proportion, until the whole is a granular mass. Succeeding this subdivision is the immediate process of the embryo's formation.

The true signification of the segmentation of the vitellus has not, I am convinced, been fully understood. Noticed first by Prevost and Dumas[†] in the frog, it has since been more carefully watched by Rusconi,[‡] Baer,[§] Bergman,[||] Ruchert,[¶] Vogt,[**] Agassiz,[††] and others of a later day. It has, until quite recently, been considered as the first grand expression of impregnation, and most certain it is, that no fecundated ovum goes on to the formation of the embryo, without first experiencing these changes. But, on the other hand, later and more extended inquiries in this wide field have shown that it occurs to a certain extent without fecundation.

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[*] *American Journal of Medical Science*, July, 1849.

[†] *Annal. des Sci. Nat.*, Tom. II. p. 129.

[‡] *Développement de la Grenouille commune.* Milan, 1826.

[§] Müller's *Archiv*, 1834, p. 481.

[||] Müller's *Archiv*, 1841, p. 89.

[¶] Müller's *Archiv*, 1841, p. 523.

[**] *Untersuchung über die Entwickelungsgeschichte von Alytes obstetricans*, 1842, p. 3.

[††] *Lectures on Embryology.* 1848.

Late morphological inquiries have shown the complete analogy existing between cells and ova, and that these same segmentary changes occur, to a certain extent, not only in the unimpregnated ovum, but in individual non-organic cells.* I have observed it with the ova of many fishes, before they have left the female, and therefore before impregnation. I have also observed its many heterogenous pathological cells, such as those of cancer, pus, &c. But, however this may be, there appears to be this difference, that in the one case they are purely abortive in their character, the segmentation rarely going on beyond twice, and here ceasing, whereas in the impregnated ovum these changes have a definite end, which is accomplished by the appearance of the new being. And it is the furtherance of this process, for this end, that characterizes the ovum from a cell, in regard to morphological changes.

Wherever it occurs in cells, it is only among the higher individual species, and may be considered an index of vitality, having no end except the production of its own species. While in the ovum and sperm-cells, the vitalizing process is more finely marked, and the cells lose their individuality by a metamorphosis into higher form or forms. And perhaps one of the best evidences that such segmentation to a definite end lies at the bottom of the primitive development of all new individual beings, is the fact that it occurs most extensively in those portions of the embryo that afford the highest expressions of the animal as such, viz. the nervous system.

Let us now take a survey of the whole matter, and the true relations of the sexes. With nearly all the processes of life, the *male* bears the marks of a higher physiological being than the female. All those functions that are characteristic of an individual isolated being are with *him* more finely pronounced than with *her*. *His* energies tend to vitalizing and animalizing processes, *hers* to a development of his by processes of a more vegetative nature. Although, in the reproductive process, the one sex is the counterpart of the other, and without each of no avail; yet I think it may be affirmed that the male exercises the higher function, and is the grand moving agent of the whole process. After the sperm-cell is produced, there occur, from forces innate, a complete set of processes, ending in the elimination of bodies which are, in a physiological sense, the miniature representatives of the whole being. And it is the function of these bodies to come in contact with the ovum, and to awake within it those dormant energies which find their expression in changes identical with those attending the elimination of the awakening body. And these forces, thus called into action by the combined agency of the two sexes, have their final expression in the elimination of a being possessing the characteristics of both.

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* This phenomenon has been quite extensively observed among vegetables. Vid. Prof. Hugo von Mohl, *Vermischte Schriften*, p. 362, et seq. Also by Griesbach, Weigman's *Archiv*, 1834. See, in addition, the works of Nägeli, Karl Müller, Schaffner, &c.

Such appears to be the philosophy of fecundation. You ask, "How is it accomplished?" I have for some time thought it might be called a kind of *Catalysis;* that is, as the magnet awakens in the iron slumbering forces like its own, so that it possesses nearly the characteristics of its awakener, so the spermatic particle, coming in simple contact (not mixing) with the ovum, awakens in the latter slumbering forces like its own, — life being the result.

We see exemplifications of this *Catalysis* in organized forms in the production of cells, having types according to their local character. And although the word may serve to cover up our ignorance, yet, as it is expressive of a power which the scientific mind by analogy only can comprehend, it may be adopted. For, after all, the *ultimata* of all science having any thing to do with vitality must ever rest on words or conditions equally as vague and unsatisfactory.

I subjoin, in a tabular form, the analogies existing between the Sperm-cell and the Ovum.

The Sperm-Cell.	*The Ovum.*
1. Is a nucleolated cell.	1. Is a nucleolated cell.
2. The nucleus, increasing and becoming granular, undergoes segmentation.	2. The nucleus (vitellus) increasing, becoming granular, undergoes segmentation.
3. The result of this segmentation is, that *each* of the subdivided cells forms a *spermatic particle.*	3. The result of this segmentation is, that *all* the subdivided cells, by a metamorphosis, form an *embryo.*
4. The function, then, of the sperm-cell, is to eliminate the vitalizing *spermatic particles.*	4. The function, then, of the ovum, is to eliminate the vitalized product, the *embryo.*
5. In the lowest sense of the term, the spermatic particle is *alive;* that is, it is an organized acting form. But it is so in the lowest sense only, since it holds no relations whatever to the external world. On this account it can never be an *animal.*	5. In the lowest sense of the term, the embryo is *alive;* that is, it is an organized acting form. But it is so in the lowest sense only, since it holds no relations whatever to the external world. It is *not an animal* until it does.

Explanation of the Plate.

FIG. 1 –.5. *Platessa Flesus;* Fig. 1, nucleolated sperm-cells in testicular cells; fig. 2, the same segmented; fig. 3, increased to the maximum and extensively segmented; fig. 4, spermatic particles in testicular cell; fig. 5, free spermatic particles.

Fig. 6 – 11. *Leuciscus chrysoleucas;* fig. 6, nucleolated sperm-cells; fig. 7, nucleus singly segmented; fig. 8, nucleus doubly segmented; fig. 9, extensive segmentation; fig. 10, free spermatic particles in parent cells, the tail most distinctly seen; fig. 11, free spermatic particles, the tail excessively minute.

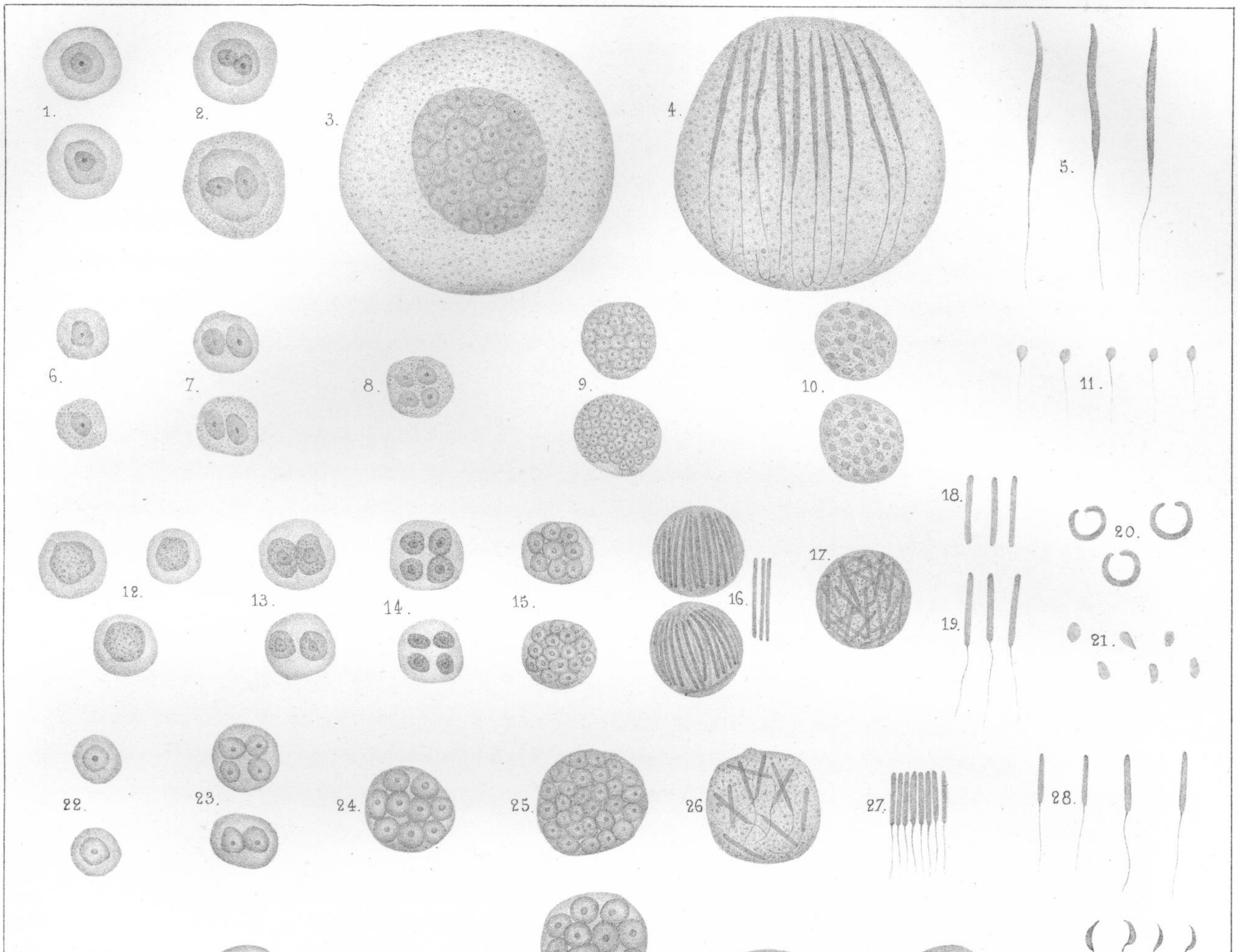
Fig. 12 – 21. *Rana pipiens;* fig. 12, spermatic ovules, with nucleus as a vitellus; fig. 13, vitellus dividing and divided; fig. 14, each still dividing, so as to make four; fig. 15, still further fissuration, so that there are eight and sixteen segments; fig. 16, spermatic particles formed in parent cells in fasciculi; fig. 17, spermatic particles formed in parent cells, scattered; fig. 18, spermatic particles without tails; fig. 19, spermatic particles with tails; fig. 20, spermatic particles curved like a hoop, no tail; fig. 21, moving, slightly caudate cells, in the field, probably escaped spermatic cells.

Fig. 22 – 28. *Columba livia;* fig. 22, nucleolated sperm-cells; fig. 23, nucleus divided and subdivided; fig. 24 and 25, still further segmented; fig. 26, free spermatic particles among granules in sperm-cells; fig. 27, spermatic particles in a fasciculus; fig. 28, free spermatic particles.

Fig. 29 – 35. *Mus decumanus;* fig. 29, nucleolated sperm-cells; fig. 30, the same increased in size with nucleus singly segmented; fig. 31, doubly segmented; fig. 32, segmentation more and more extensive; fig. 33, eight spermatic particles in sperm-cell; fig. 34, four spermatic particles in sperm-cell; — in both cases they have probably been developed out of or in cells, and assumed this disposition from convenience; fig. 35, free sickle-shaped spermatic particles.

Fig. 36 – 41. *Sciurus hudsonicus;* fig. 36, nucleolated sperm-cells; fig. 37, singly segmented; fig. 38, doubly segmented; fig. 39, extensive segmentation; fig. 40, spermatic particles with thin, broad, disk-like anterior extremity, containing granules; fig. 41, the same seen sideways to show the thinness.

Fig. 42 – 48. *Ovis aries;* fig. 42, nucleolated sperm-cells; fig. 43, the same described; fig. 44 and 45, still further segmented; fig. 46, spermatic particles free in sperm-cells; fig. 47, spermatic particles in a fasciculus in sperm-cell; fig. 48, free spermatic particles.



A. Sonrel from Dr Burnett's drawings.

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